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Nutritional Value of Parsley Roots Depending on Nitrogen and Magnesium Fertilization

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Abstract: Parsley is an herb/vegetable rich in nutritional compounds such as carbohydrates, vitamins, protein, crude fiber, minerals (especially potassium), phosphorus, magnesium, calcium, iron, and essential oils. Limited information is available in the literature on the quality of parsley roots depending on the cultivation technology used in the form of macronutrients and micronutrients, preparations to stimulate plant growth and development, as well as plant-protection products. A three-year study was undertaken to determine the effect of applying mineral fertilization with nitrogen, including magnesium on the nutritional value of parsley roots in terms of the content of ascorbic acid, total and reducing sugars, and minerals: (total N, K, Mg, Ca). The research material was the root of *Petroselinum crispum* ssp. *tuberosum* from an experiment where nitrogen was applied in soil at (0, 40, 80, 120 kg N ha^{-1}) and magnesium at (0, 30 kg MgO ha^{-1}). Nitrogen fertilization increased the nutritional value in terms of total and reducing sugars, as well as total N and Ca content. Applied magnesium fertilization caused a significant increase in the content of all tested nutrients. The most total sugars (127.7 g kg^{-1} f. m.), reducing sugars (16.8 g kg^{-1} f. m.), and total N (12.13 g kg^{-1} d. m.) were accumulated by roots from the object where nitrogen was applied at a maximum rate of 120 kg N ha^{-1}, including magnesium. On the other hand, for the content of K (19.09 g kg^{-1} d. m.) in the roots, a dose of 80 N ha^{-1} was sufficient. For ascorbic acid (263.2 g kg^{-1} f. m.) and Ca (0.461 g kg^{-1} d. m.), a dose of 40 kg N ha^{-1} with a constant fertilization of 30 kg MgO ha^{-1} was sufficient. When applying high doses of nitrogen, lower doses of magnesium are recommended. This is sufficient due to the high nutritional value of parsley roots. Due to the worsening magnesium deficiency in soils in recent years, the use of this nutrient in the cultivation of root vegetables is as justified and timely as possible. Quality-assessment studies of root vegetables should be continued with higher amounts of magnesium fertilization. Different ways of applying magnesium in parsley cultivation should also be tested.

Keywords: parsley roots; nutrients; elements; application; nitrogen; magnesium

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1. Introduction

Parsley (*Petroselinum crispum* [Mill] Nym) is a species of biennial plant in the celery family (*Apiaceae*) [1,2]. It is classified among the herbs/vegetables that are used to improve the sensory qualities of food [2–5]. Depending on economic use, different varieties and types of parsley are grown. For fleshy and thick tap roots, *Petroselinum crispum* ssp. *tuberosum* (turnip or Hamburg type) is grown, and for leaves, *Petroselinum crispum* ssp. *crispum* (with smooth and curly leaves) is grown [6–8]. In Poland, *Petroselinum crispum* ssp. *tuberosum* (turnip-rooted or Hamburg type) is mainly grown on a commercial scale for harvesting both roots and leaves. The cultivation of leafy varieties is secondary [9]. The roots and leaves are available on the market all year round. They are consumed raw, cooked, and in processed form [10,11]. All parts of the parsley plant (leaves, stems, and roots) are rich in health-promoting compounds, minerals (especially potassium, phosphorus, magnesium, calcium, and iron), crude fiber, protein, and essential oils [9,12–15]. Parsley also contains carbohydrates such as sucrose, glucose, rhamnose, mannose, arabinose, and mannitol [16].

The good quality of parsley can be ensured by cultivation in the right position and well-chosen agrotechnology [17]. Parsley is a vegetable with relatively low soil requirements, so it is generally grown on light soils. These soils are characterized by a low abundance of organic matter and magnesium. The very intensive cultivation carried out in recent decades has placed more emphasis on nitrogen, phosphorus, and potassium fertilization than on magnesium fertilization [18]. This led to the depletion of Mg reserves in soils and large-scale Mg deficiency [19]. Yağmur et al. [20] report that the poor quality and yellowing of vegetable leaves is due not only to a deficiency in the soil of nitrogen but also a deficiency of magnesium. In order to obtain the intense green color of parsley leaves in its cultivation, high nitrogen fertilization is used. Chenard et al. [21] and Wang et al. [19] point out that for optimal yields of good-quality economically important horticultural crops, it is advisable to use not only nitrogen but also magnesium fertilization in their cultivation. Magnesium can significantly affect the uptake and utilization of nitrogen, the enhancement of photosynthesis, and the production of assimilates and their partitioning between plant parts [18]. However, it is important to remember that the uptake of magnesium from the soil by plants depends on the amount of readily available Mg in the soil [22]. In addition, it also depends on the ratio of levels of exchangeable cations: calcium, magnesium, potassium, sodium, and ammonium [23,24]. The application of auxiliary nutrients (Mg) to crops can alter the ability of plants to access and utilize nitrogen. In addition, the use of parsley cultivation technology with additional magnesium fertilization does not significantly increase the cost of its production. On the other hand, it brings great benefits to the health of the consumer [18,20]. Considering the above-mentioned factors, the magnesium fertilization of parsley crops, especially on light soils, should prove very effective [19,25].

The nutrients supplied during cultivation perform specific functions in the plant. Nitrogen is a component of proteins and protein enzymes, thus playing an important role in the construction of plant tissues and the activation of metabolic processes [26]. Magnesium, as an essential component of the chlorophyll particle, participates in the process of photosynthesis and enters the structure of ribosomes that plays a major role in protein synthesis [27]. It also takes an active part in carbohydrate synthesis by inducing the activity of phosphorylating enzymes in starch transport and also determines the disease resistance of plants during the epiphytic period [27,28]. Among other things, potassium determines the plant's starch, protein, sugars, and pectin and plays an important role in the opening and closing of the stomata. Calcium, on the other hand, is the main component of the central lamella (Ca-pectin) of the cell wall. It strengthens cell walls, and it is involved in cell elongation and division, membrane permeability, and the activation of several key enzymes [1,29]. Thus, it is rational in vegetable cultivation to implement agrotechnical practices that result in an additional supply of nutrients. This leads to an increase in their quality as a raw material for food production [30,31]. However, it should be remembered that the content of these components in the plant depends not only on the amount and type of fertilizer but also on its form [10,32].

The health risks posed by the use of synthetic compounds in food [33,34], and the clear consumer preference for natural and safe foods, indicate that research related to determining the quality of plant raw materials as a base for food production is still very important and useful [35,36]. Scientific reports on parsley quality focus mainly on the leaves. Due to the scarcity of information on the effect of the use of mineral fertilization in the cultivation of parsley in relation to the quality of its roots, research was undertaken in this area. The purpose of the study was to determine the effect of varying nitrogen fertilization applied together with magnesium on the content of sugars, Vitamin C, and elements determining the nutritional value of parsley roots.

2. Materials and Methods

2.1. Study Area

The research material was a late variety of root parsley (*Petroselinum crispum* ssp. *tuberosum*)—Halblange Berliner (Figure 1). Parsley was sampled from a field experiment conducted at the Wierzchucinek Research Station (2013–2015) belonging to the Faculty of Agriculture and Biotechnology of the Bydgoszcz University of Science and Technology (53°26′ N, 17°79′ E).

Figure 1. Field experiment with root parsley.

2.2. Soil

The field experiment was conducted on light, slightly acidic soil (pH in KCl 5.9–6.2)—the pH value in 1 M KCl (POCH S.A., Gliwice, Poland) was determined by potentiometric method PN-ISO [37]. The soil was characterized by low levels of bioavailable P [29–34 mg kg^{-1}] soil] (PN-R-04023 [38]) and K [54–62 mg kg^{-1} soil] [39] and medium levels of bioavailable Mg [36–42 mg kg^{-1} soil] [40].

2.3. Treatment Details

The research was conducted using a strict two-factor field experiment in a randomized block design in three replicates. The experiment included 24 fertilizer sites with a plot area equal to 12 m^2.

In the field experiment, different amounts of nitrogen (Factor I) were applied to the soil: 0 (control), 40 (before sowing), 80 (40—before sowing and 40—in the three-leaf phase), 120 (40—before sowing, 40—in the three leaf phase and 40—in the nine-leaf phase) kg N ha^{-1} in the form of ammonium nitrate—34%, and magnesium (Factor II); 0 (control) and 30 (before sowing) kg MgO ha^{-1} in the form of magnesium sulfate—16%. In addition, constant levels of fertilization with phosphorus (100 kg P_2O_5 ha^{-1}) and potassium (150 kg K_2O ha^{-1}) were applied. Parsley sowing was done annually by hand in the first decade of April, sowing 3 kg of seeds per hectare. The row spacing in the plots was 30 cm. Prior to sowing, the seeds were treated with Funaben T, and tillage and crop protection treatments were applied in accordance with current agronomic requirements. Weed control was conducted manually with crop protection products. The roots were harvested at the stage of their full maturity (from October 1 to 10) after the plants had reached their full development—the root had reached its typical size and shape (BBCH 49). Averaged root samples (5 kg) were obtained from each plot for laboratory testing.

2.4. Weather Conditions

Table 1 presents the distribution of precipitation and air temperature for the study years (2013–2015) and for the multi-year period (1953–2012). During the entire 2013 and 2014 growing seasons, with the exception of August and September (2013), air temperatures were higher than in the multi-year period. In contrast, in every month of the 2015 growing season except August, air temperatures were very close to the multi-year period. Excessive precipitation was recorded in May and September in 2013, while the 2015 growing season received significantly less precipitation than the multi-year total.

Laboratory analyses included determination of the following contents in the fresh root mass: ascorbic acid, total sugars, and reducing sugars. On the other hand, the content of mineral elements (total N, Mg, K, Ca) was determined in dry material (lyophilized).

Table 1. Average monthly air temperature and total precipitation in 2013–2015 and in the multi-year period 1953–2012.

Month	Air Temperature (°C)				Rainfall (mm)			
	2013	2014	2015	1953–2012	2013	2014	2015	1953–2012
April	13.6	9.9	7.5	7.4	7.0	40.7	15.6	27.2
May	14.2	13.3	12.4	12.9	91.7	65.7	21.6	43.9
June	17.4	16.0	15.7	16.2	49.3	44.9	33.0	54.4
July	18.9	21.5	18.5	18.0	79.0	55.4	50.4	72.9
August	18.1	17.2	20.9	17.5	56.6	57.3	20.3	55.8
September	10.7	14.4	13.8	13.2	64.1	25.9	52.4	40.8
October	8.2	9.6	6.4	8.3	18.6	18.0	20.9	31.9
Mean (air temp.) Sum (rain.)	14.4	14.6	13.6	13.4	366.3	307.9	214.2	326.9

2.5. Parsley Root Sublimation Drying

Medium-sized parsley roots were washed and cut into pieces 0.5 × 0.5 cm in size. Root samples (200 g) prepared in this way were placed for 48 h in a Whirlpool AFG 6402 E-B (Pero, Milano, Italy) freezer at −22 °C. The freeze-drying process was conducted in a CHRIST ALPHA 1–4 LSC (Osterode am Harz, Germany). Freeze-dryer operating parameters: condenser temperature 55 °C, vacuum 4 kPA at 20 °C. Parsley root samples were dried to constant weight when the final water content of the material was less than 2%. Drying was conducted for 24 h. The dried samples were stored in sealed LDPE packages in a vacuum desiccator.

2.6. Analysis of Ascorbic Acid

Analysis of ascorbic acid was conducted according to Kapur et al. [41]. Twenty-five grams of a homogeneous sample of raw parsley roots were homogenized with 50 mL of metaphosphoric acid/acetic acid (Chempur, Piekary Śląskie, Poland). The solution was quantitatively transferred to a 100 mL volumetric flask, supplemented with the metaphosphoric acid/acetic acid solution and mixed. The resulting solution was filtered through Whatman filter paper (International Limited, Kent, UK) and then centrifuged on a centrifuge (Hettina Zentrifugen, Rotina 420 R, Schönwalde-Glien, Germany) at 3500 rpm for 15 min. To oxidize L-ascorbic acid, 4 mL of supernatant were placed into a glass tube, 0.23 mL of 3% bromine water (Chempur, Piekary Śląskie, Poland) were added, and then 0.13 mL of 10% thiourea (POCH S.A., Gliwice, Poland) were added to remove excess bromine. The prepared sample was kept at 37 °C in a thermostatic bath for three hours. After this time, the samples were cooled in an ice bath for 30 min. To the cooled sample, 5 mL of cooled 85% H_2SO_4 (Chempur, Piekary Śląskie, Poland) were added with constant stirring. The absorbance of the solution was measured at 521 nm, in 1 × 1 cm thick cuvettes using a SHIMADZU UV-1800, UV-Vis Spectral Photometer System (Nishinokyo Kuwabara-cho, Nakagyo-ku, Kyoto, Japan). A calibration curve in the concentration range of 0–1000 mg kg^{-1} was prepared using L-ascorbic acid solution (Chempur, Piekary Śląskie, Poland). The results are presented in g kg^{-1} of fresh root mass.

2.7. Analysis of Sugars

The content of total sugars and reducing sugars was conducted according to the G-26 test using the colorimetric method [42]. A homogeneous sample of fresh parsley roots (10 g) was put into a 250 mL volumetric flask, and 150 mL of distilled water were added. The sample prepared in this way was shaken vigorously for 30 min on a table shaker. The flask was then filled to the mark with distilled water, stirred, and its content was filtered through Whatman filter paper (International Limited, Kent, UK). For the determination of reducing sugars, 1 mL of filtrate was put into a glass tube and 3 mL of DNP reagent (Sigma Aldrich, St. Louis, MO, USA) were added. The samples were vigorously shaken for 10 s and then heated in a boiling water bath for 6 min. After heating, the samples were cooled in cold water and absorbances were measured at 600 nm. For the determination, 1 × 1 cm cuvettes and a SHIMADZU UV-1800, UV-Vis Spectral Photometer System (Nishinokyo Kuwabara-cho, Nakagyo-ku, Kyoto, Japan) were used. For the determination of total sugars, 40 mL of filtrate were measured into 100 mL conical flasks, then the solution was acidified with 36% HCl (Chempur, Piekary Śląskie, Poland). The flask with the solution was covered with aluminum foil and heated in a boiling water bath for 30 min. After heating, the samples were cooled, and then 30% NaOH (POCH S.A., Gliwice, Poland) was added to neutralize the reaction of the solution. Then, 1 mL of the solution was placed into glass tubes, 3 mL of DNP reagent were added, and the procedure for the determination of reducing sugars was followed. A calibration curve was prepared using glucose (Chempur, Piekary Śląskie, Poland). The results are presented in g kg^{-1} of fresh root mass.

2.8. Analysis of Elements

The content of total nitrogen (Ntot) [43] was determined based on a modified Berthelot reaction (Skalar method). In brief, after dialysis against a buffer solution of pH 5.2, ammonia in the sample is chlorinated to monochloramine, which reacts with salicylate to form 5-aminosalicylate. Following oxidation and oxidative coupling, a green complex is formed. The absorption of the complex is measured at 660 nm (Skalar SANplus flow analyser, Breda, The Netherlands). To measure the total level of K, Ca, and Mg, lyophilized material (1.5 g) was mineralized at 550 °C for 6 h. The material was dissolved in 2 mL of 0.15 M HNO_3 (Chempur, Piekary Śląskie, Poland). Magnesium levels were measured by Atomic Absorption Spectrometry (SpectraAA-250Plus, Varian, Markham, ON, Canada), and potassium and calcium contents were measured by flame emission spectroscopy. Plant material chemical analyses were based on the SSSA methodological guide [44]. Nutrient uptake was calculated by multiplying the nutrient concentration by the amount of root tuber dry matter (DM values available from the authors).

2.9. Statistical Analysis

The experimental results on the chemical composition of parsley roots were statistically processed using Statistica 13.1 software (StatSoft, Tulsa, OK, USA). Data were verified for normality of distribution using the Shapiro–Wilk test and homogeneity of variance. Mean values obtained in each group were subjected to two-way ANOVA (analysis of variance). Values are presented as means with standard deviations. Categorized 3W diagrams were used for subsets of the data to present the results. To determine the relationship between the qualitative traits studied, Spearman's rank correlation coefficients were determined at $p = 0.05$ and multiple regression analysis was performed. The original data of the 2013, 2014, and 2015 trial have been presented in the Supplementary Materials of measurement data.

3. Results and Discussion

3.1. Ascorbic Acid

Ascorbic acid is one of the most important compounds necessary for humans, which the body itself cannot synthesize [9]. According to many authors, the varieties and morphological parts of parsley differ significantly in Vitamin C content, and the leaves contain the most Vitamin C [3,6,7,9,45,46]. In our study, the content of ascorbic acid in the roots of the studied variety after harvest, regardless of the experimental factors, averaged 253.7 mg kg^{-1} f. m. (Table 2). Dobričević et al. [9] showed that the average content of Vitamin C in the roots of six parsley varieties was 153.0 mg kg^{-1} f. m. The roots of the Halblange variety contained the most Vitamin C: 269.0 mg kg^{-1} f. m., which was comparable to the content obtained for this variety in our own research (Table 2). Since ascorbic acid is a derivative of glucose, it is expected that plant tissues with a higher rate of photosynthesis will synthesize more Vitamin C [47]. Fernandes et al. [15], studying 25 parsley varieties, obtained an average Vitamin C content of 0.24 in the varieties with smooth leaves, 0.30 for varieties with fluted leaves, and 0.39 mg kg^{-1} d. m. for root parsley varieties. Teuscher et al. [17], Santos et al. [46], and Najla et al. [6] showed that fresh parsley leaves contain 1.2 to 4.0 g kg^{-1}, 592 mg kg^{-1}, and 1.3 to 2.6 g kg^{-1} of Vitamin C, respectively, and the variety with smooth leaves contains the most Vitamin C. On the other hand, Osińska et al. [48] report that the vitamin C content of parsley significantly depends not only on the variety but also on the harvest date. Delaying the harvest date does not always lead to the accumulation of more of this vitamin. Of the three varieties studied, the leaves of the Festival variety contained the most Vitamin C—2.91 g kg^{-1} f. m. In contrast, in the study of Karklelienė et al. [7], the leaves of the Festival variety contained 1.54 g kg^{-1} f. m. of ascorbic acid, almost half as much as in the study of Osińska et al. [48]. This indicates that the Vitamin C content of parsley is also affected by where it is grown [11].

Table 2. Ascorbic acid content in parsley roots depending on nitrogen and magnesium fertilization [mg kg^{-1} of fresh matter].

Fertilization N [kg ha^{-1}]	Fertilization MgO [kg ha^{-1}]		
	0	30	Mean
0	256.1 ± 3.5	272.9 ± 3.8	264.5 ± 11.9
40	252.4 ± 11.0	263.2 ± 8.1	257.8 ± 7.6
80	238.2 ± 10.1	260.6 ± 7.6	249.4 ± 15.8
120	230.2 ± 7.3	256.0 ± 6.5	243.1 ± 18.2
Mean	244.2 ± 12.1	263.2 ± 7.1	253.7 ± 13.4
[2] LSD α = 0.05	[1] A = 8.37 B = 5.35 A/B = N. S.		
$p \leq 0.05$	y = 255.1140 − 0.1816N + 0.6313MgO; r^2 = 0.713		

[1] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses. [2] LSD—least significant difference, N. S.—not significant.

Our study showed a significant effect of both nitrogen and magnesium fertilization on Vitamin C content in parsley roots, which is confirmed by the analysis of variance (Tables 2 and 3). The applied increasing doses of nitrogen fertilization significantly reduced the concentration of Vitamin C in roots (ascorbic acid = 255.114 − 0.1816N + 0.6313MgO; r^2 = 0.713; $p \leq 0.05$) (Table 2). The regression equation indicates a greater effect of magnesium fertilization on ascorbic acid content. The lowest reduction in Vitamin C content of 2.5% was obtained after applying nitrogen at a rate of 40 kg ha^{-1}. On the other hand, the greatest decrease in Vitamin C content of 8.1% was obtained after applying the highest nitrogen dose of 120 kg ha^{-1} (Table 2). There is a significant relationship between soil nitrogen content and the content of Vitamin C and ascorbate in parsley roots [49,50]. Vitamin C content was significantly lower in parsley grown on mineral fertilization compared to those grown on organic and organic–mineral fertilization by 20 and 22.5%, respectively [49]. Readily available nitrogen from mineral fertilizers can limit the synthesis of secondary metabolites [51–53]. Obtaining such a result may also be a consequence of the lower content of enzymes responsible for the synthesis of ascorbic acid in plants grown on mineral fertilization [50]. However, when the nitrogen content in the soil is low, ascorbic acid accumulation may increase [54]. Zhang et al. [55] and Hesari et al. [56] point to the key role of optimizing nitrogen fertilization to maximize Vitamin C content as high nitrate supply triggers the expression of ascorbate–glutathione cycle genes. In addition, Wszelaczyńska et al. [57] and Fernandes et al. [58] report that fertilization, especially unbalanced fertilization and on light soils, can temporarily or permanently change soil fertility. This leads to their acidification and nutrient depletion and, consequently, to a decrease in the productivity and quality of the crops grown. The Vitamin C content of parsley is influenced not only by the rate of application but also by the method and timing of nitrogen fertilization [32]. In the authors' study, parsley contained the most Vitamin C after applying half the nitrogen dose pre-sowing and the other half in two equal post-harvest doses—immediately after the next leaf harvest.

Table 3. Analysis of variance (ANOVA) of measurement data of nutrient content in parsley roots.

		df	MS	F%
Ascorbic acid	[1] A	3	1587	<0.001
	B	1	6456	<0.001
	A × B	3	193	0.024
Total sugars	A	3	25	<0.001
	B	1	53	<0.001
	A × B	3	3	<0.001
Reducing sugars	A	3	841	<0.001
	B	1	6750	<0.001
	A × B	3	14	0.018
Ntot	A	3	43,345	<0.001
	B	1	1637	<0.001
	A × B	3	55	0.001
Mg	A	3	0.613	<0.001
	B	1	2.223	<0.001
	A × B	3	0.02	N. S.
K	A	3	2.88	<0.001
	B	1	4.62	<0.001
	A × B	3	0	N. S.
Ca	A	3	0.002	N. S.
	B	1	0.035	<0.001
	A × B	3	0.001	N. S.

[1] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses. N. S.—no significant.

The applied magnesium fertilization in our study increased the Vitamin C content of parsley roots by 7.2%, which was confirmed by the regression coefficient described above (Table 2). The positive effect of magnesium fertilization on the Vitamin C content of vegetables has been reported by other researchers [28,59,60]. Applying magnesium at doses of 45 and 90 kg MgO ha^{-1} in carrot cultivation resulted in an increase in ascorbic acid content in roots by 12.1 and 11%, respectively, compared to the control [59]. Yağmur et al., 2021 [60] showed a positive effect of magnesium fertilization on the content of Vitamin C in parsley leaves. The maximum Vitamin C content was characterized by leaves after fertilization with a dose of 200 kg MgO ha^{-1}. Importantly, at this rate, the increase in ascorbic acid content in the leaves compared to the control was highly significant ($p < 0.001$). This indicates that higher magnesium fertilization should be used in vegetable cultivation for high Vitamin C content in their roots. Providing plants with magnesium increases the process of photosynthesis and, thus, magnesium plays a direct part in the synthesis of sugars necessary for the production of secondary metabolites (Vitamin C) [28].

3.2. Total Sugars and Reducing Sugars

Sugars are considered key components of vegetable quality due to the role they play in sensory and nutritional properties. In our study, regardless of the experimental factors, the average content of total sugars and reducing sugars in the roots of the variety studied was 109.6 and 14.3 g kg^{-1} f. m., respectively, which corresponds to 468.7 and 61.9 g kg^{-1} d. m. (Table 4). In our study, the content of total sugars was comparable with the few literature data. Khali et al. [61], conducting research with parsley *Petroselinum crispum,* showed that the carbohydrate content of its roots was 104 g kg^{-1} f. m. In contrast, Knez et al. [11] report that the average carbohydrate content of parsley roots is 105.0 g kg^{-1} f. m. In a study by Petropoulos et al. [62], the average content of total sugars in the roots of 17 parsley varieties was 245.0 g kg^{-1} d. m. and reducing sugars was 93.2 g kg^{-1} d. m. Of the genotypes tested, the parsley roots of the Kaśka variety contained significantly the most total sugars at 278.2 g kg^{-1} d. m. and the least of the Berlinski Halblange Springer variety at 205 g kg^{-1} d. m. compared to the other varieties tested. Halblange varieties contained, on average, half as much total sugars, i.e., 240.2 g kg^{-1} d. m., compared to our study. In contrast, the content of reducing sugars was at a similar level, i.e., 62.4 g kg^{-1} d. m. (Table 4). Pokluda [63], studying five parsley varieties, showed an average content of reducing sugars in roots of 93.0 g kg^{-1} d. m. The authors showed that the propensity to accumulate total sugars as well as reducing sugars is a varietal trait. Fernandes et al. [15], studying five parsley varieties with smooth leaves, three varieties with fluted leaves, and 17 root varieties, did not observe significant differences in terms of total leaf sugars among the three types of varieties. However, they noted significant differences in reducing sugars.

Table 4. Total sugars and reducing sugars content in parsley roots depending on nitrogen and magnesium fertilization [g kg^{-1} of fresh matter].

Fertilization N [kg ha^{-1}]	Total Sugars [g kg^{-1} f. m.]			Reducing Sugars [g kg^{-1} f. m.]		
	Fertilization MgO [kg ha^{-1}]					
	0	30	Mean	0	30	Mean
0	92.9 ± 3.0	111.3 ± 3.0	102.1 ± 13.0	12.5 ± 0.3	13.2 ± 0.3	12.9 ± 0.5
40	95.5 ± 1.6	116.3 ± 2.5	105.9 ± 14.7	13.1 ± 0.3	14.7 ± 0.4	13.9 ± 1.1
80	104.2 ± 2.2	121.7 ± 2.6	113.0 ± 12.4	14.0 ± 0.3	15.9 ± 0.5	15.0 ± 1.4
120	106.8 ± 2.3	127.7 ± 3.7	117.3 ± 14.8	14.3 ± 0.2	16.8 ± 0.6	15.6 ± 1.8
Mean	99.9 ± 5.9	119.3 ± 7.1	109.6 ± 6.2	13.5 ± 0.8	15.2 ± 1.6	14.3 ± 1.2
[2] LSD α = 0.05	[1] A = 6.88 B = 3.09 A/B = N. S.			A = 0.68 B = 0.54 A/B = 0.42		
$p \leq 0.05$	y = 92.0010 + 0.1314N + 0.6455MgO; r^2 = 0.944;			y = 12.0999 + 0.0227 + N + 0.0572MgO; r^2 = 0.866		

[1] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses. [2] LSD—least significant difference, N. S.—no significant.

Analysis of variance of own results showed that the content of total and reducing sugars significantly depended on the factors used (Table 3). Both nitrogen and magnesium fertilization caused a significant increase in sugar content (total sugars = 92.001 + 0.1314N + 0.6455MgO; r^2 = 0.944; $p \leq 0.05$; reducing sugars = 12.0999 + 0.02271N + 0.0572MgO; r^2 = 0.866; $p \leq 0.05$) (Table 4). The regression equation indicates that nitrogen and magnesium fertilization had a greater effect on the content of total sugars than reducing sugars. At the same time, a greater effect of magnesium fertilization was observed on the content of these components compared to nitrogen. The obtained percentages of explained variability (expressed by coefficients of determination, r^2) of the content of total and reducing sugars equal 94.4% and 86.6%, respectively, testifying to the usefulness of the obtained results in breeding work on parsley. The highest concentration of total and reducing sugars was characterized by roots after parsley was fertilized with a dose of 120 kg N ha^{-1} (113.7 and 15.6 g kg^{-1} f. m., respectively). At this dose, the increase in total and reducing sugars relative to the control averaged 14.9 and 20.9%, respectively (Table 4). In addition, Spearman's rank correlation analysis conducted indicates a significant relationship between total N content and total and reducing sugars, respectively, r = 0.652 and r = 0.692 $p < 0.01$ (Table 5). However, after magnesium fertilization, the content of total sugars and reducing sugars was 119.3 and 15.2 g kg^{-1} f. m., respectively. The obtained increase in the content of total and reducing sugars was 19.4 and 12.6%, respectively (Table 4). From the point of view of nutritional value, this is very beneficial. It should be noted that the highest content of total and reducing sugars was obtained after the application of nitrogen at 120 kg N ha^{-1} and magnesium at 30 kg MgO ha^{-1}: 127.7 g kg^{-1} f. m. and 16.8 g kg^{-1} f. m., respectively (Table 4). The total soluble sugar level in fleshy radish roots was highest after the application of nitrogen, together with magnesium [64]. Their results show that the content of soluble sugars was highest after the application of nitrogen and magnesium in the amount of 0.300 g and 0.050 g, respectively. On the other hand, using a higher dose of magnesium fertilization of 0.100 g, the authors obtained a significant reduction in the content of soluble sugars. Nitrogen and magnesium are the most important macronutrients that determine the allocation of reserve elements in plants (carbohydrate metabolism). Their introduction into the soil is often insufficient or imbalanced [64]. This causes an imbalance in the distribution of cations in plants, limiting the size and quality of yields. However, it should be noted that when magnesium is used in excess, nutrient stress affects the photosynthetic and physiological properties of plants, leading to a delay in their growth and development. On the other hand, magnesium deficiency leads to the accumulation of sugars in the above-ground parts of plants and reduces their transport to the roots of vegetables [18,65]. Therefore, the dose of magnesium used in our study is reasonable.

Table 5. The correlation coefficients (r) according to the rank order of Spearman between the studied parameters.

Parameters	Total Sugars	N	Mg	Ca
[1] Ascorbic acid	0.303 **	0.233 *		0.317 **
[1] Total sugars	0.852 **	0.692 **		0.392 **
[1] Reducing sugars		0.652 **		0.513 **
[2] N			0.349 **	0.509 **
[2] K			0.879 **	0.522 **
[2] Mg				0.563 **

Significance levels are represented as * $p < 0.05$; ** $p < 0.01$ [1] fresh mass content, [2] dry matter content.

3.3. Elements

The effect of nitrogen and magnesium fertilization on the content of total nitrogen, magnesium, potassium, and calcium in parsley roots is provided in Table 6 and Figures 2–5. The total N content of parsley roots averaged 10.98 g kg^{-1} d. m. (2.54 g kg^{-1} f. m.) (Table 6, Figure 2). Głodowska and Krawczyk [66] report that the nitrogen content of parsley roots averages 13.27 g kg^{-1} d. m. and, thus, is higher compared to our study. The concentration of total N in parsley leaves is higher compared to the compactness in its roots [10,20,21,66]. Our study showed that the average content of Mg, K, and Ca in root dry matter was 4.14, (0.96 g kg^{-1} f. m.) 18.87, (4.36 g kg^{-1} f. m.) and 0.431 g kg^{-1} (0.100 f. m.), respectively (Table 6, Figures 3–5). In a study by Głodowska and Krawczyk [66], the contents of these macronutrients in roots were 21.40, 1.97, and 1.94 g kg^{-1} d. m., respectively. Pokluda [67] reports that the content of K in the fresh mass of parsley roots is at 4.69 g kg^{-1}, the Mg content is at 0.509 g kg^{-1}, and the Ca content is at 0.124 g kg^{-1} f. m. The content of K, Mg, and Ca, as well as total N, is much higher in leaves than in roots [20,21,66].

Table 6. Mineral content in parsley roots depending on nitrogen and magnesium fertilization [g kg^{-1} of dry matter].

Fertilization N [kg ha^{-1}]	Ntot		Magnesium		Potassium		Calcium	
	Fertilization MgO [kg ha^{-1}]							
	0	30	0	30	0	30	0	30
0	9.71 ± 0.5	10.17 ± 0.6	4.30 ± 0.60	4.58 ± 0.53	19.11 ± 0.96	19.77 ± 1.19	0.404 ± 0.026	0.436 ± 0.031
40	10.15 ± 0.5	11.51 ± 1.0	3.86 ± 0.67	4.30 ± 0.55	18.73 ± 1.11	18.78 ± 0.99	0.423 ± 0.036	0.461 ± 0.029
80	10.79 ± 0.6	11.91 ± 1.1	3.88 ± 0.67	4.24 ± 0.59	18.48 ± 1.29	19.09 ± 1.16	0.406 ± 0.034	0.459 ± 0.033
120	11.46 ± 0.8	12.13 ± 0.3	3.9 ± 0.89	4.24 ± 0.86	18.14 ± 1.46	18.84 ± 1.79	0.403 ± 0.040	0.457 ± 0.034

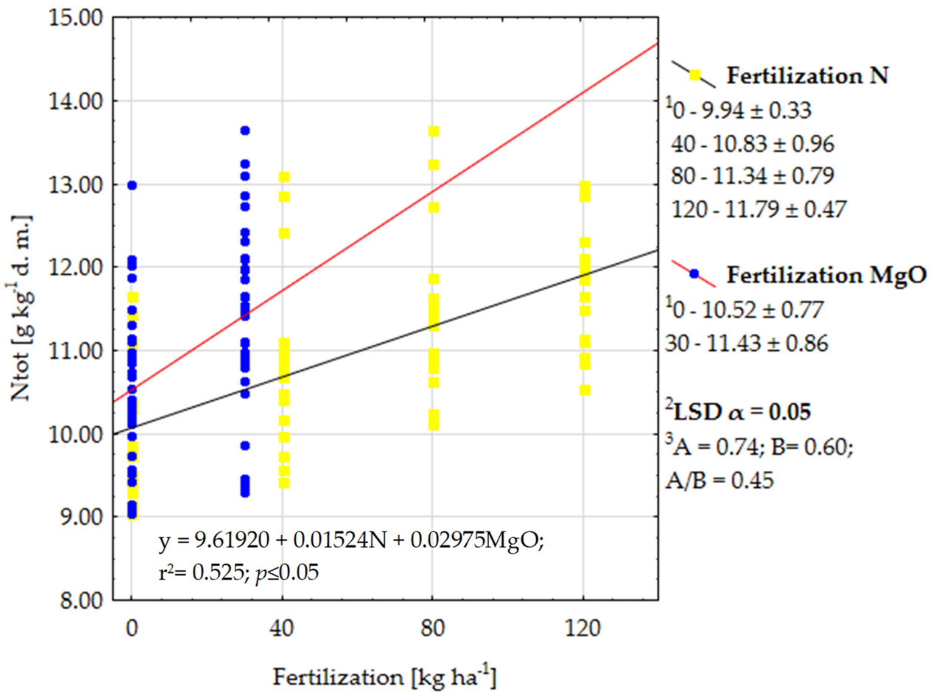

Figure 2. Scatter plot of Ntot content in parsley roots in relation to nitrogen and magnesium fertilization [g kg^{-1} of dry matter]. [1] Mean Ntot content; [2] LSD—least significant difference; [3] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses.

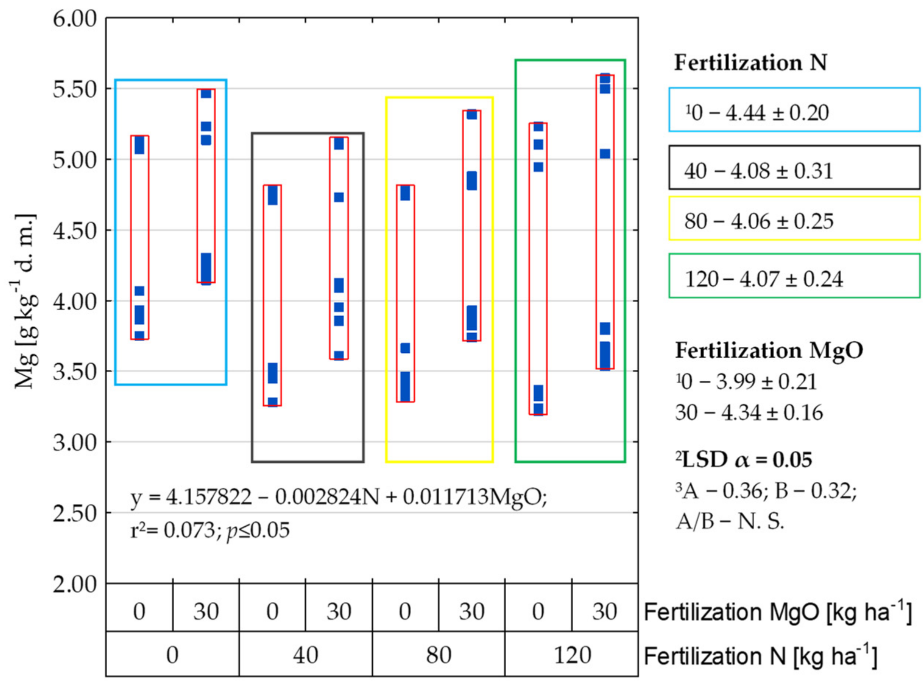

Figure 3. Mg content in parsley roots depending on nitrogen and magnesium fertilization [g kg^{-1} of dry matter]. [1] Mean Mg content, [2] LSD—least significant difference, N. S.—no significant; [3] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses.

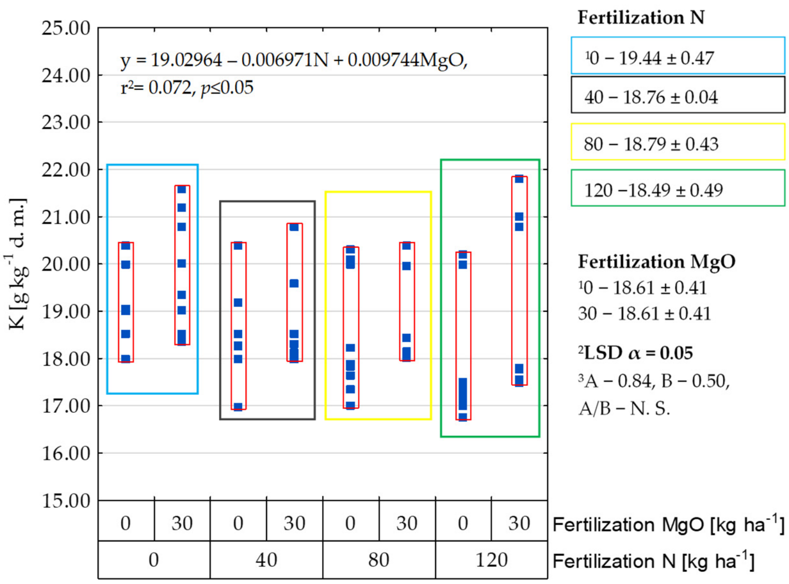

Figure 4. K content in parsley roots depending on nitrogen and magnesium fertilization [g kg^{-1} of dry matter]. [1] Mean K content, [2] LSD—least significant difference, N. S.—no significant; [3] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses.

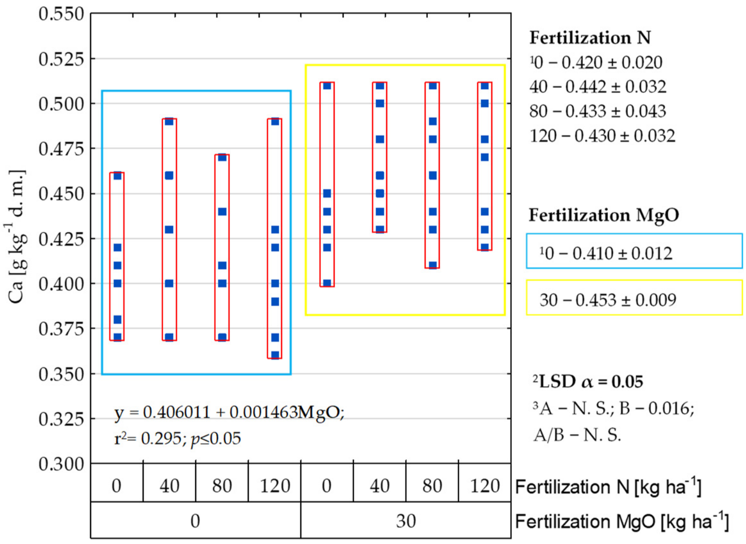

Figure 5. Ca content in parsley roots depending on nitrogen and magnesium fertilization [g kg^{-1} of dry matter]. [1] Mean Ca content, [2] LSD—least significant difference, N. S.—no significant; [3] Experiment factors: A—nitrogen fertilization doses, B—magnesium fertilization doses.

The analysis of variance conducted indicates that nitrogen fertilization has a significant effect on the content of Ntot, K, and Mg (Table 3). The applied increasing doses of nitrogen caused a significant increase in the content of total N in parsley roots (total N = 9.61920 + 0.01524N + 0.02975MgO; r^2 = 0.525; $p \leq 0.05$) (Figure 2). The highest content of total N was obtained after the application of 120 kg kg^{-1} N ha^{-1}—11.79 g kg^{-1} d. m. The increase in total N content was 18.6% compared to the control. There was also a slight increase in Ca content, but it has not been statistically proven. This is also confirmed by the calculated correlation coefficient between total N and Ca content r = 509 (p = 0.01) (Table 5). The highest Ca content was characterized by roots fertilized with a dose of 40 kg N ha^{-1} (Table 6, Figure 5). In addition, increasing doses of nitrogen fertilization caused a significant linear decrease in the concentration of Mg and K with respect to the control (Figures 3 and 4). The decrease in content for K was greatest at a dose of

120 kg N ha^{-1} and was 4.9%. For Mg, the greatest reduction in content was obtained at a dose of 80 kg N ha^{-1} and was 8.6%. While the effect of nitrogen fertilization on the content of the studied nutrients in the roots was inconclusive, the applied magnesium fertilization caused a significant increase in the concentration of all macronutrients (Table 6, Figures 2–5). After the application of magnesium fertilization, there was an increase in total N by 8.6%, K by 2.7%, Mg by 4.3%, and Ca by as much as 10.5% compared to the control (Table 6, Figures 2–5). Yağmur et al. [20] showed that the application of varying doses of nitrogen, as well as magnesium fertilization, affects the concentration of nutrients in parsley. The authors obtained the highest content of total N after applying doses of 220 and 250 kg N ha^{-1}, and further raising the dose caused the concentration of this element to decrease significantly. On the other hand, the authors obtained the highest content of K, Ca, and Mg at a rate of 220 kg N ha^{-1}. It is known that the concentration of nutrients in vegetables increases only up to a certain level of nitrogen fertilization [59,68]. However, macronutrient concentrations in the Yağmur et al. [20] study are at higher levels than in our own study. These differences may be due to genetics as the authors conducted their study with the Gigante D'Italia parsley variety. Chenard et al. [21], conducting pot experiments with parsley *Petroselinum crispum* Nym of the Dark Green Italian variety by applying different amounts of nitrogen to the soil (6 to 105 mg N L^{-1}), obtained a significantly linear increase in N ($p \leq 0.01$) and K content ($p = 0.003$). In contrast, in response to increasing soil N concentrations, Mg ($p \leq 0.001$) and Ca ($p \leq 0.001$) content in leaves initially decreased and then increased. Kincses et al. [69] report that the nutrient content of parsley *Petroselinum tuberosum* also depends on the type of soil on which the crop is grown. After applying differential nitrogen fertilization on heavy soil—chernozem and light soil—sandy soil, they obtained a significant increase in total N content only on light soil. In contrast, they showed no effect of nitrogen fertilization on the K content of parsley regardless of the soil on which they cultivated.

The applied magnesium doses in the study of Yağmur et al. [20] caused a significant increase in Ntot content and a highly significant increase in Mg content in parsley leaves. They showed the highest Ntot content at a dose of 280 kg MgO ha^{-1}, and a dose of 200 kg MgO ha^{-1}, was sufficient for the highest Mg content. Doses above 200 kg MgO ha^{-1} caused a significant decrease in this element. As opposed to our study, the authors showed no effect of magnesium fertilization on K and Ca content. Głodowska and Krawczyk [66] showed that after parsley was cultivated with conventional technology, its roots and leaves contained a lower content of macronutrients (N, Mg, K, and Ca) compared to organic cultivation. The exception was the Ca content of the leaves in conventional cultivation. The disparate literature data on the macronutrient content of parsley are a result of the lack of a balanced supply of nutrients after mineral fertilization [64,66].

4. Conclusions

Root vegetables are an important part of the diet of many people around the world. Recently, there has been an increase in the consumption of root parsley, so its nutritional value plays an important role. Therefore, it is very important to look for cultivation technology that will guarantee the highest quality. Research indicates that in order to obtain the high nutritional value of parsley roots, in addition to basic NPK mineral fertilization, magnesium fertilization should be applied. The application of nitrogen to parsley roots increased the content of total and reducing sugars, total N and Ca, and decreased the content of K and Mg. The highest content of total and reducing sugars and total N was observed when nitrogen was applied at a rate of 120 kg ha^{-1}. In contrast, the application of nitrogen at a rate of 80 kg ha^{-1} resulted in the least reduction in the content of K, and for Mg, it was at a rate of 40 kg ha^{-1}. In contrast, the applied magnesium fertilization at a rate of 30 kg MgO ha^{-1} resulted in a significant increase in the content of all the nutritional value components studied. The positive effect of the simultaneous application of nitrogen and magnesium on the nutritional value of parsley roots was demonstrated. When high nitrogen doses are applied, lower magnesium doses are recommended. Due to the scarcity of reports on the quality of parsley roots depending on cultivation technology, research in this direction should be deepened.

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